Naval Submarine Medical Research Laboratory

NSMRL Report 1161 7 December 1990

PRELIMINARY INVESTIGATION ON THE UTILITY OF SATURATION AND BRIGHTNESS AS REDUNDANT AND NON-REDUNDANT CODES WITH HUE IN TACTICAL DISPLAYS

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NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
REPORT NO. 1161

Naval Medical Research and Development Command
Research Work Unit No. 65856N-M0100.001-5003

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SUMMARY PAGE

THE PROBLEM

As part of an effort to examine the full range of stimulus dimensions which are effective as additional information codes in tactical display symbologies, two experiments were conducted to determine the utility of saturation and brightness as redundant and non-redundant codes with hue. Previous research indicates that saturation and hue are related in such a way that redundant coding might result in a facilitation in search performance on a visual display. The dimension of brightness has received some attention as a possible information code, however previous research has not focused on symbols with self-luminous characteristics, and interactions with other dimensions have not been adequately addressed. The ability of individuals to search for target stimuli on a tactical display was assessed.

THE FINDINGS

The addition of saturation level as a redundant code to diamond shaped symbols of red, blue and yellow hues offered no advantage in terms of search time and search accuracy. When coding was non-redundant, subjects had significantly slower search times and less accurate responses when asked to search for symbols of specific saturation levels. Redundant and non-redundant coding with brightness level yielded similar results, with the exception that subjects were significantly slower when searching for targets of medium brightness levels.

APPLICATION

It is recommended that only one saturation level per dominant wavelength be utilized in tactical displays; spectral and desaturated hues of the same dominant wavelength should be avoided. The results also suggest that brightness might be an effective code if used in a partially redundant manner and limited to two luminance levels. Experiments are currently underway to test this supposition. Overall, the results are consistent with previous recommendations to maximize differences between colors to facilitate discrimination and thus search performance.

ADMINISTRATIVE INFORMATION

This research was conducted under Naval Medical Research and Development Command Research Work Unit 65856N-M0100.001-5003. This report was submitted for review on 10 September 1990, approved for publication on 7 December 1990, and has been designated as NSMRL Report No. 1161.

ABSTRACT

Two experiments were conducted to assess the relative benefits of redundantly and non-redundantly combining the stimulus dimensions of saturation and brightness with hue in symbolic visual displays. Previous research has indicated that both saturation and brightness may be related to hue in such a way that a facilitation in search performance might be realized if these dimensions were combined in a tactical display symbology. Subjects completed extensive visual search paradigms on CRT based tactical displays. In experiment 1, three hues (red, blue, and yellow) and three saturation levels (most, middle, and least saturated) were varied, while symbol shape was held constant. The stimulus combinations of hue and saturation were combined in redundant and non-redundant conditions, which enabled the quantification of the integrality and separability of the hue and saturation dimensions. The analysis of the search reaction times and the number of correct responses revealed a significant interference effect when the stimulus dimensions were combined in a non-redundant manner and the subjects were forced to search for targets of a specific saturation level. Compared to simple one dimensional search conditions, search performance was not improved when saturation was redundantly coded with hue, thus an integral facilitation effect was absent from the data. Based on the results of experiment 1, the use of different saturation levels within a hue may be ill-advised for applications in military tactical displays and civilian air traffic control. The presence of interference without facilitation argues for the exclusion of saturation as a separate or redundant coding dimension in tactical displays. In experiment 2, the three hues were varied with three stimulus brightness levels. The results were similar to those of experiment one, except that the interference effect in the non-redundant coding condition was due primarily to the medium brightness levels. If restricted to two levels, brightness might be a useful redundant code. Overall, the results lend support to algorithms that work to maximize color differences (in the CIE space) for use in visual displays.

INTRODUCTION

Several experiments have established that the addition of color to NTDS (Naval Tactical Display Set) symbols of maritime tactical displays significantly decreases search speed and increases accuracy (Jacobsen, et al., 1985; 1986). With the advent of high resolution color graphics systems, and given the power of color in the perceptual domain, the use of color in various military displays is inevitable. While a shift from monochromatic to colored NTDS symbols may be forthcoming, newly developed symbology types are using color coding to fill and redundantly code with symbol shape (NATO STANAG 4420, 1990). Within this framework of redundant coding, considerable interest lies in determining what other stimulus dimensions can be used to extract and highlight additional information in a hierarchical manner in symbolic displays. However, great care must be taken when introducing new dimensions as redundant codes in visual displays, since it has been shown that there are known costs, or decrements, in some aspects of performance associated with redundant color coding of NTDS symbols (DiVita, et al., 1989).

In order to extract and fully define the relationship between color and other stimulus dimensions, DiVita et al. (1989) have utilized a constrained classification sorting task to investigate the integrality/separability of stimulus dimensions. Briefly, when stimulus dimensions are integrally related, they form a mental gestalt which can facilitate and/or interfere with an individuals ability to group or classify the stimuli. If two dimensions are redundantly coded, and they are integrally related, individuals will sort and classify the stimuli faster than they would have if just one of the dimensions were presented alone. However, if the dimensions are uncorrelated, or coding is not redundant, individuals will be unable to ignore one of the dimensions, and will take longer to sort or classify stimuli. These facilitation and interference effects, common to integrally related stimulus dimensions, are absent for separable dimensions. When stimulus dimensions are separable, individuals can selectively attend to one dimension and completely filter out the other, so interference and facilitation do not occur. For a thorough review of this topic, see Garner (1974).

Using a constrained classification card sorting task, DiVita et al. (1989) have observed that pairs of the NTDS dimensions shape (or identity), closure (subdivisions of shape dimension, denoted by presenting a full or partial outline of the symbol), and color are separably related. However, when all three dimensions are present and varied systematically, shape and closure display an integral interference effect. These results highlight the need for caution when additional stimulus dimensions are considered for a symbology, and argue for the application of an experimental design which quantifies the integrality/separability of different stimulus dimensions. Experiments 1 and 2 apply such a design for the investigation of the relationship between saturation and brightness, respectively, with hue.

Experiment 1

Garner and Felfoldy (1970) demonstrated that hue and saturation were integrally related stimulus dimensions through the use of a constrained classification card sorting paradigm. Redundant and non-redundant coding of these dimensions resulted in facilitation and interference effects, respectively. It is important to examine this effect within the context of tactical display symbologies, since saturation may be proposed as an additional redundant or partially redundant stimulus code with symbol hue. The present study utilized a visual search methodology on a raster-scan cathode ray (CRT) screen with the hue and saturation of the display symbols presented in a redundant and non-redundant manner, and permitted the calculation of the decree of separability and integrality between these dimensions.

Methods

Subjects: Seven subjects (4 male, 3 female) voluntarily participated. They ranged in age from 22 to 35 years. All had normal color vision, and those subjects who wore corrective lenses did so during the experiment. While several subjects had previous experience with tactical plots, no experience was necessary to complete the search tasks described below.

Apparatus: A Ramtek 9400/91 graphics generator and display system was controlled by a Digital Equipment Corp. VAX 730 computer. the 19" color CRT display had a pixel resolution of 1280 by 1024 pixels (100 pixels per inch). The CRT monitor was calibrated with a Photo Research SpectraScan spectral radiometer. Responses were made via a four choice response panel. Diamond shaped symbols, of double pixel width were 0.5 cm in length on each edge (approximately 0.4° visual angle). Chromaticities of the stimuli are shown in Table 1. Because of heterogeneities in perceived saturation, particularly for stimuli of approximately 570 nm (Boynton, 1979), the desaturated values for each hue were obtained by the method of adjustment from several laboratory personnel. Likewise, the luminances of the yellow hues were increased in an attempt to equilibrate perceived saturation across hues.

TABLE 1: SATURATION AND HUE EXPERIMENT

Symbol CIE Coordinates and Luminances

u′, v′ (cd/m²)

Saturation Level	*Red*	*Blue*	*Yellow*
Most Saturated	.404, .525 (0.22)	.180, .245 (0.11)	.228, .547 (0.57)
Mid Saturated	.317, .513 (0.23)	.183, .340 (0.22)	.230, .531 (0.62)
Least Saturated	.274, .503 (0.26)	.200, .397 (0.21)	.230, .514 (0.54)

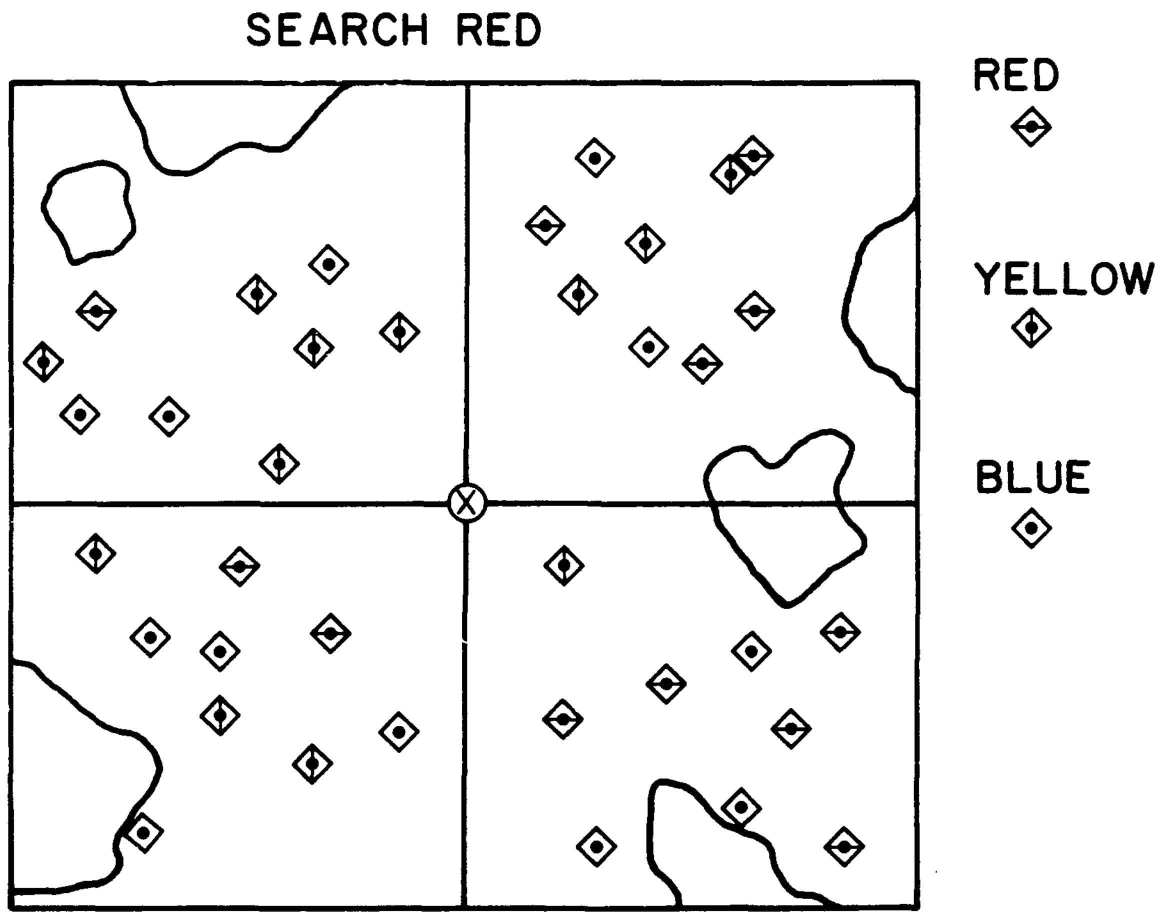

Figure 1. A representative screen from the experiment. Symbols were diamond shapes with a dot in the center. The horizontal and vertical lines through symbols denoting "red" and "yellow" were added to this plot for demonstration purposes, since color prints are not available. Land masses and plot perimeter were outlined in green, ownship was magenta, and the quadrant boundaries were gray. All symbol types displayed on the screen were always defined in the key in terms of color, or saturation level, depending upon the condition.

Procedure: On each trial, subjects viewed a geographical plot with ocean and peripheral land areas outlined in green, as shown in Figure 1. This portion of the CRT screen measured 17 x 16 cm. Ownship was placed at the center of the plot, and had vertical and horizontal lines extending from it to the edge of the plot in order to demarcate four quadrants on the screen. The search condition was written over the top of the plot, instructing the subject to locate the quadrant of the plot with the greatest number of red, blue, yellow, least saturated, mid-saturated, or most saturated symbols. Each geographical "screen" contained 36 symbols, equally divided into each quadrant. Sixty-nine symbol configurations were available to each stimulus set condition for assignment of hue and saturation, as described below. The symbol configurations were randomly selected for each individual trial, with the restriction that configurations never appeared in succession. The symbol configurations were superimposed on one of three land/sea maps. No subject ever reported remembering a particular configuration. The number of target symbols in a given quadrant could vary from five to nine. A key to the right of the geographical plot provided the subject with a definition of each symbol shown on the screen. Pilot studies revealed a need for such a key, specifically when subjects were required to search for a target of a particular saturation level.

There were three overall stimulus sets; one dimensional, correlated, and uncorrelated. Within each stimulus set, there were two overall search conditions; search on color (red, blue, yellow), and search on saturation (most, middle, least saturated). In the one dimensional - search on color condition, the red, blue, and yellow symbols were composed of the most saturated hues. For the search on saturation condition of the one dimensional stimulus set, the symbols were a red hue, and varied in three levels of saturation; blue and yellow hues were not used in the one dimensional condition.

In the correlated stimulus set - search on color condition, the red symbols contained the most saturated red hue, the yellows were of a mid-saturated level, and the blue symbols were composed of the least saturated blue hue. For the correlated - search on saturation condition, these same stimuli were used, however the subject was instructed to search according to saturation level.

The uncorrelated stimulus set presented the subject with the entire set of stimuli: each hue at all three levels of saturation. Again, the subject was instructed to search on color and search on saturation. With all stimulus combinations present, the subject had to selectively attend to three stimulus levels within a given stimulus class: In a search for the quadrant with the greatest number of red symbols, the subject had to consider red symbols of all three saturation levels. Accordingly, while search for medium saturated symbols, the subject had to search across all three hues. By definition, integrally related stimulus dimensions would yield faster search times in the correlated configuration compared to the one dimensional configuration (facilitation), but should show slower search times in the uncorrelated configuration (interference).

Identical procedures were administered in one practice and one experimental session to each subject. The six conditions (two search conditions within each stimulus set) were randomized for every subject. Within each search condition, subjects always received the same order of search situations for colors (first red, then blue, followed by yellow), and saturations (most, followed by middle and least saturated). Subjects completed 20 searches for each specific color or saturation, although the first 5 reaction times were not recorded. Thus, a total of 45 searches were recorded for each subject for each of the six search conditions. Additionally, the first condition was always repeated at the end of the session. Breaks were provided at the completion of every two search conditions.

Results and Discussion

The geometric mean of the search times and the average number of correct responses were calculated for each search situation for every subject. Randomized block factorial analysis procedures with three levels of STIMULUS SET (one dimensional, correlated, and uncorrelated), two levels of SORTING DIMENSION (search on color, search on saturation), and three levels of SEARCH SITUATION (specific red, blue, yellow, or most, middle, and least saturation level) were used to analyze the data (Kirk, 1982). Separate analyses were run for the reaction time and number correct data. The analysis of variance (ANOVA) summary table for the reaction time analysis is shown in Table 2. STIMULUS SET interacted significantly with SORTING DIMENSION, while SEARCH SITUATION was not a significant variable in the analysis. The reaction time results are plotted in Figure 2. A post-hoc (Tukey HSD) investigation of the STIMULUS SET x SORTING DIMENSION interaction indicated that, when collapsed across specific SEARCH SITUATIONS, the reaction times from the uncorrelated - search on saturation condition were significantly slower than the reaction times of all other conditions ($p < .05$). The analysis also revealed that the one dimensional - search on saturation reaction times were significantly slower than the one dimensional - search on color, and correlated - search on color, conditions ($p < .05$). Additionally, the differences among the means for the one dimensional - search on color, correlated - search on color, correlated search on saturation, and uncorrelated - search on color reactions times were not statistically significant.

The ANOVA summary table for the number of correct responses analysis is shown in Table 2, and the data is plotted in Figure 3. The significant triple interaction of STIMULUS SET, SORTING DIMENSION, and SEARCH CONDITION was due primarily to the low number of correct scores within the uncorrelated - search on saturation condition. Post-hoc tests revealed significant differences between the means for the uncorrelated - search on saturation condition (collapsed across specific search situations) compared to mean number correct responses from the uncorrelated - search on color, and both correlated search conditions ($p < .01$). The differences among the means for the one dimensional - search on color, correlated search on saturation, and uncorrelated - search on color were not statistically significant.

<u>**TABLE 2: SATURATION AND HUE ANALYSES**</u>

Reaction Time ANOVA Summary

variables	*s.s.*	*d.f.*	*F values*
STIMSET	31.22	2	35.89***
SORTDIM	19.17	1	44.07***
SEARCH	1.61	2	1.84
STIMSET X SORTDIM	12.93	2	14.87***
STIMSET X SEARCH	1.12	4	0.64
SORTDIM X SEARCH	2.27	2	2.62
STIMSET X SORTDIM X SEARCH	1.96	4	1.13
residual	44.35	102	

Number Correct ANOVA Summary

variables	*s.s.*	*d.f.*	*F values*
STIMSET	182.92	2	46.66***
SORTDIM	180.96	1	92.33***
SEARCH	14.16	2	3.61*
STIMSET X SORTDIM	152.44	2	38.89***
STIMSET X SEARCH	34.89	4	4.45**
SORTDIM X SEARCH	45.78	2	11.68***
STIMSET X SORTDIM X SEARCH	22.89	4	2.91*
residual	200.02	102	

significance levels: * $p < .05$; ** $p < .01$; *** $p < .001$

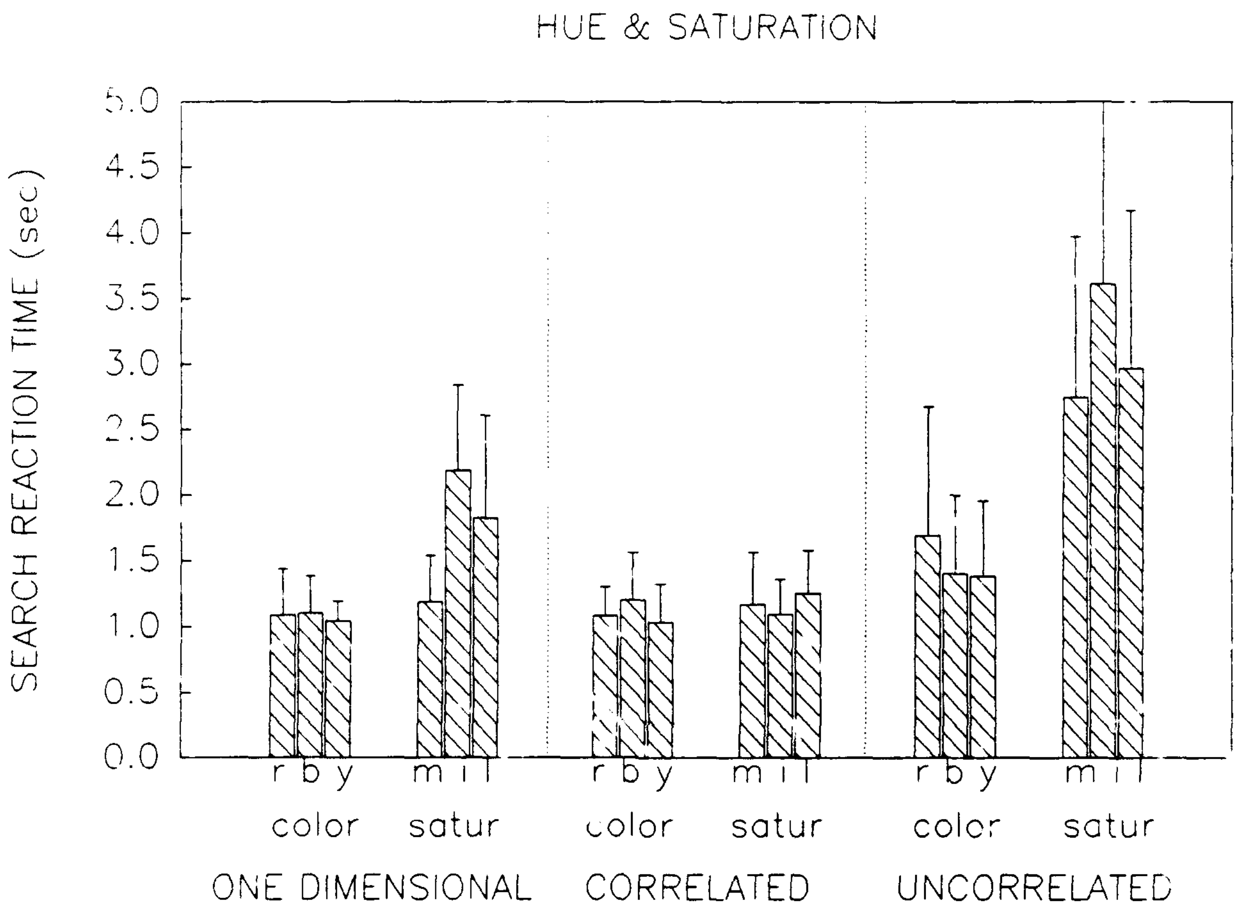

Figure 2. Mean search reaction times (in seconds) plotted as a function of search condition for the saturation and hue stimulus dimensions. The symbols "r, b, and y" indicate search times for symbols of red, blue and yellow hues, respectively. The symbols "m, i, and l" indicate search times for symbols of most, intermediate, and least saturated levels. Error bars represent one standard deviation from the mean. For the one dimensional condition, the search on color stimuli were of the most saturated hues, while the search on saturation stimuli were confined to the red hue. For the correlated conditions, red stimuli were of the most saturated level, yellow stimuli were of a mid-saturated level, and blue stimuli were composed of the least saturated blue hue. The uncorrelated condition presented stimuli composed of all possible hue and saturation combinations, such that subjects always had to look across three levels of a dimension in any particular search situation.

The interference effect in the data was the result of slower response times and not a greater number of incorrect responses in the uncorrelated - search on saturation condition. Within this condition, the data indicate that even though subjects took much more time to respond, they were still performing just slightly better than chance. Subjects were required to search for targets of a particular saturation level that varied in hue, and the powerful grouping effect of hue made this particular search condition extremely difficult. Response times and accuracy scores for the uncorrelated - search on color conditions were not significantly different compared to the one dimensional and correlated search on color conditions. Thus, although interference is a hallmark of integrally related stimulus dimensions, it might be incorrect to conclude that hue and saturation were truly integrally related in the present paradigm. Another important finding of the present results is the lack of a facilitation effect under the correlated, or redundant coding, condition. Garner and Felfoldy (1970) observed facilitation, as well as interference, in their study on hue and saturation. Several important differences between their study and the present experiment are worth noting. Perhaps of greatest importance is the fact that they used the card sorting paradigm, which presented the stimuli one at a time to the subjects, while a visual search/grouping paradigm was used in the present study, which presented all possible stimuli simultaneously. Julesz (1965) has demonstrated that the discriminability of colored textures is based upon the ability of the visual system to cluster or group hues together, and this clustering is difficult for "nonadjacent" hues like red and green, or blue and yellow. The serial stimulus presentation procedure of the card sorting paradigm is free from this kind of effect.

Another important difference between the Garner and Felfoldy experiment and the present paradigm lies in the number of levels used within a dimension. Garner and Felfoldy varied two well divided levels within hue and saturation, while three levels were examined in this study.

Based on the saturation and hue results, the use of different saturation levels within a hue may be ill-advised for application in military tactical and civilian air traffic control displays. Redundantly coding saturation and hue offered no search performance advantage. The difficulty of searching for targets of a particular saturation level when hue was free to vary argues against using saturation as a separate, non-redundant, symbology code.

Figure 3. Mean number correct plotted as a function of search condition for the saturation and hue data. Error bars represent one standard deviation from the mean.

Experiment 2

Brightness can be a powerful stimulus dimension in terms of search performance. However, the ability of brightness to serve as an attentional attractor is likely dependent upon the magnitude of luminance differences among the stimuli. On color raster-scan monitors, the luminance range of the display is set by the sum output of the three color guns and their respective phosphor characteristics. As more saturated colors are desired, luminous output becomes limited by the outputs of individual guns/phosphors, thus restricting the luminous range of the monitor in general. Another restriction on the luminance range comes from the requirement to perceive a symbol of low luminance on the screen. Tactical displays are generally viewed under subdued lighting, in concert with other graphics display systems, and the overall illumination of the area can set the lower bounds on the symbol luminance range. Thus, while brightness may well be a powerful stimulus, its utility as a redundant code with hue on a CRT monitor needs clarification.

Eriksen (1952, 1953) conducted search experiments in which stimulus shape, hue, brightness, and size were varied. His search results indicated that multi-coded stimuli were generally found faster than unidimensional stimuli, but the experimental designs did not permit an analysis of the degree to which each dimension contributed to facilitation and interference effects when combined with other dimensions. Additionally, the dimensions contained numerous levels, and hue and saturation were coded by the placement of a Munsell chip on a cardboard shape, making comparisons to self-luminous colored shapes difficult.

Newman and Davis (1961) investigated the dimensions of hue, brightness and flashing in a detection task using a projection display to produce self-luminous symbols. However, their study is of limited relevance because in all conditions coding was non-redundant with symbol shape; there was never a redundant coding pattern to which the subject could become accustomed. Additionally, Newman and Davis never combined levels of brightness with three levels of color, and they also used a very large number of symbols (36) in their display.

Methods

Subjects: Eight subjects (5 men and 3 women), ranging in age from 22 to 35 years voluntarily participated in the experiment. All subjects had normal color vision and could wear they eye glasses if necessary.

Apparatus: The equipment was identical to experiment 1, with the exception of the CRT monitor. The CRT was identical in every respect to the CRT used in the first experiment, however it had been modified to achieve higher luminance levels.

Procedure: The experimental design and procedure was identical to that used in experiment 1, with the exception that three levels of brightness replaced the saturation dimension. The symbol CIE chromaticities and luminance levels are specified in Table 3. One dimensional hues were of the highest luminance level, and the one dimensional - brightness search hue was red. In the correlated condition, red symbols were always of the highest luminance, blue and yellow symbol luminances were set at medium and low levels, respectively.

TABLE 3: BRIGHTNESS AND HUE EXPERIMENT

Symbol CIE Coordinates and Luminances

u', v' (cd/m^2)

Brightness Level	*Red*	*Blue*	*Yellow*
Brightest	.419, .530 (1.10)	.172, .179 (1.04)	.247, .549 (1.33)
Middle Bright	.419, .531 (0.59)	.172, .187 (0.57)	.261, .548 (0.80)
Dimmest	.420, .530 (0.23)	.172, .189 (0.12)	.286, .545 (0.35)

TABLE 4: BRIGHTNESS AND HUE ANALYSES

Reaction Time ANOVA Summary

variables	*s.s.*	*d.f.*	*F values*
STIMSET	75.54	2	23.35***
SORTDIM	76.07	1	46.96***
SEARCH	14.61	2	4.51*
STIMSET X SORTDIM	67.90	2	20.96***
STIMSET X SEARCH	12.73	4	1.96
SORTDIM X SEARCH	23.18	2	7.15***
STIMSET X SORTDIM X SEARCH	14.58	4	2.25
residual	245.14	119	

Number Correct ANOVA Summary

variables	*s.s.*	*d.f.*	*F values*
STIMSET	143.04	2	50.01***
SORTDIM	177.78	1	124.3 ***
SEARCH	31.45	2	11.03***
STIMSET X SORTDIM	144.18	2	50.41***
STIMSET X SEARCH	21.67	4	3.79**
SORTDIM X SEARCH	29.43	2	10.29***
STIMSET X SORTDIM X SEARCH	18.86	4	3.30**
residual	169.93	119	

significance levels: * $p < .05$; ** $p < .01$; *** $p < .001$

Results and Discussion

The geometric mean of the search times and the average number of correct responses were calculated for each search situation for every subject. The data were analyzed by separate reaction time and number correct STIMULUS SET (one dimensional, correlated, uncorrelated) by SORTING DIMENSION (search on color, search on brightness level) by SEARCH SITUATION (specific red, blue, yellow, or brightest, middle, and dimmest brightness level) repeated measures analysis of variance (ANOVA) procedures. The ANOVA summary table for the reaction time analysis is shown in Table 4. Search reaction time is plotted as a function of search configuration in Figure 4. STIMULUS SET interacted significantly with SORTING DIMENSION, and SORTING DIMENSION interacted significantly with SEARCH SITUATION. Tukey HSD post-hoc tests indicated that the STIMULUS SET x SORTING DIMENSION interaction wa: ?ue to prolonged brightness search times (collapsed across specific search situations) within the uncorrelated condition ($p < .05$), while all other searches based on symbol color or brightness were undifferentiated as a function of condition. Post-hoc tests also indicated that the SORTING DIMENSION x SEARCH SITUATION interaction was the result of (collapsed across one dimensional, correlated and uncorrelated conditions) significant differences in reaction times when subjects were tasked with searching for targets of the middle brightness level ($p < .05$). No significant reaction time differences were found for searches on the specific hues of red, blue, and yellow.

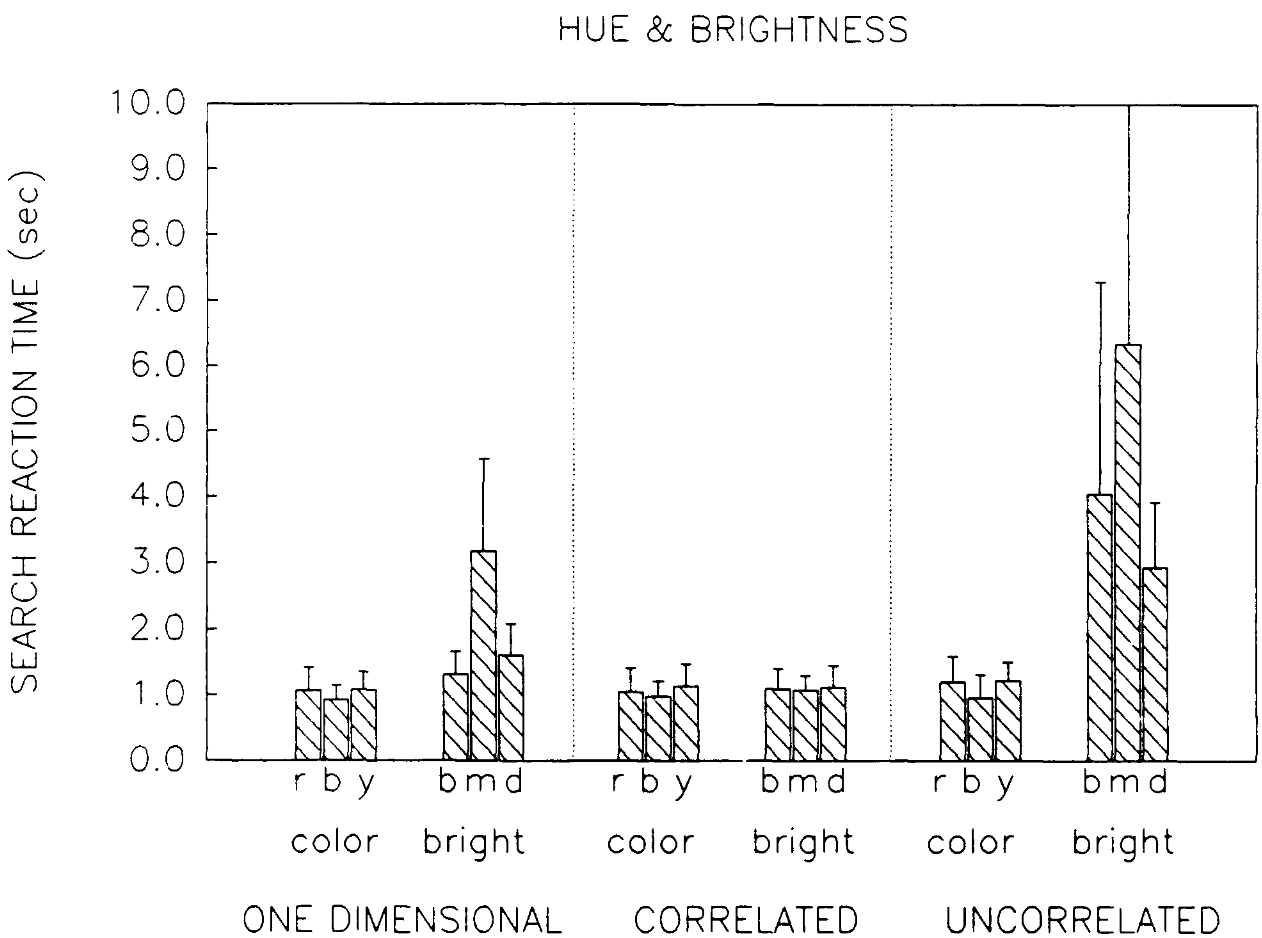

Figure 4. Mean search reaction times (in seconds) plotted as a function of search condition for the brightness and hue dimensions. The symbols "b, m, and d" indicate search times for display symbols of brightest, middle brightness, and dimmest levels. All else as in Figure 2.

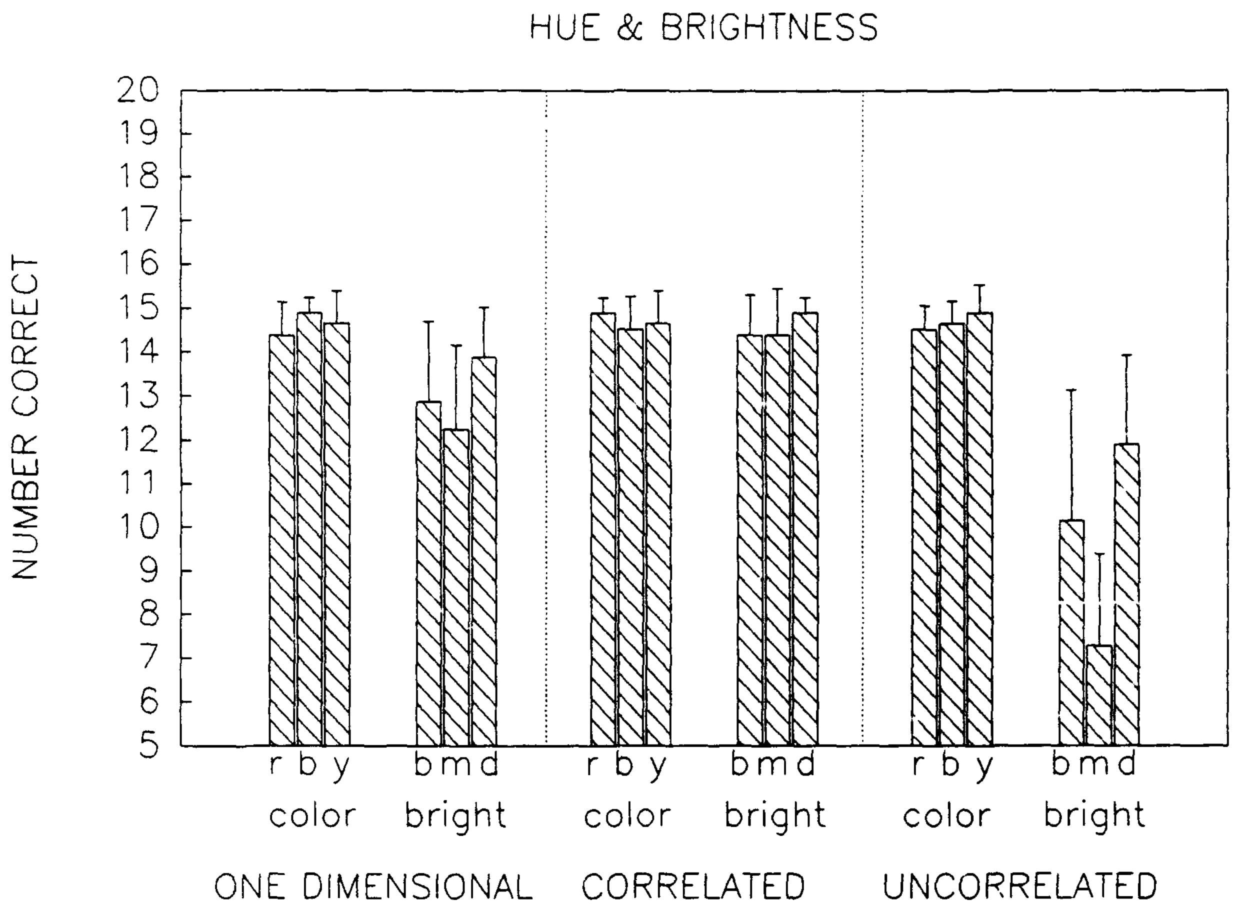

Figure 5. Mean number correct plotted as a function of search condition for the brightness and hue. Error bars represent one standard deviation from the mean.

The ANOVA summary table for the number of correct responses analysis is shown in Table 4, and the data is plotted in Figure 5. The significant triple interaction of STIMULUS SET, SORTING DIMENSION, and SEARCH CONDITION was due primarily to the low number of correct scores within the uncorrelated - search on brightness condition. Post-hoc tests revealed significant differences between the means for the uncorrelated - search on brightness condition (collapsed across specific search situations) compared to the mean number of correct responses from all other conditions ($p < .05$). Within the uncorrelated - search on brightness condition, the number of correct responses for the middle brightness level was significantly lower than the scores for the brightest and dimmest symbols ($p < .05$).

Overall, the brightness and hue data showed no facilitation effect when redundantly coded in the correlated condition; response times and number of correct responses were undifferentiated with like measures of the one dimensional condition. In the uncorrelated condition, subjects only showed an interference effect when tasked with searching for targets of a particular brightness level. This is not surprising, given the powerful effect of hue; each brightness level in the uncorrelated condition contained each of the three hues, making the search task quite difficult. Conversely, when subjects were asked to search for targets of a specific hue (of which each contained targets of all three brightness levels), subjects performed as well as if the targets were of equivalent brightness.

The analysis of the data indicated that searching for targets of the middle brightness level presented the most difficult challenge. The exception to this finding is the correlated condition, where subjects most likely realized the correlated relationship within the dimensions and achieved the brightness search by simply searching on target hue. These results suggest that if the brightness dimension had been restricted to two well separated luminance levels, the interference effect might be reduced.

GENERAL DISCUSSION

The manner in which saturation and brightness relate with hue in a visual display consisting of self-luminous symbols was investigated using a modified constrained classification task (DiVita et al., 1989; Garner, 1974) in order to determine if either stimulus dimension might be a useful additional information code in maritime tactical displays. The saturation and hue data demonstrated a strong interference effect when subjects were tasked with searching for targets of a given saturation level but composed of different hues. These results were supportive of previous recommendations to maximize color discriminability in visual displays (Carter and Carter, 1981; 1982) and algorithms that are specifically designed to achieve this goal for a specified set of colors in the CIELUV space (Silverstein et al., 1986). The addition of brightness as a redundant code with hue did not result in faster search times. This is presumably because the hues were easily discriminable even in the one dimensional case when all were of equivalent luminances, and, thus, any further separation of the stimuli in the CIE color space would not result in any appreciable reduction in search times.

Subjects tasked with searching for targets of middle brightness levels in the uncorrelated condition showed the greatest decrement in performance compared to corresponding searches for targets of low and high luminance levels. This is a particularly important difference between the brightness and saturation experiments; uncorrelated searches on saturation were uniformly poor. If brightness had been restricted to two levels, would the interference effect be reduced, and would a facilitation effect in the correlated condition arise? The brightness results suggest that some stimulus dimensions may be binary in nature; for all intents and purposes the dimension is either on or off. Temporal modulation, or blinking, of symbols may be another dimension in which the presentation of more than two well separated levels leads to severe performance decrements. Current experiments (Van Orden et al., 1990) are investigating the utility of brightness and temporal flashing as partially-redundant codes in complex tactical displays using a greater representation of the NTDS symbol set, with general symbol shape redundantly coded with hue.

At a fundamental level, the guided visual search model proposed by Wolfe, Cave and Franzel (1989) may be of relevance to ongoing investigations of potential information codes for tactical displays. The guided search model postulates that a preattentive, parallel search stage guides an attentionally demanding serial search processor to locate target stimuli imbedded in noise. Performance by the faster parallel processing stage is enhanced when stimulus salience is maximized. Once pointed in the right direction by the parallel processor, serial search can be carried out in an efficient manner. One goal of the present and future research endeavors is to improve parallel and serial searching efficiency for symbols of interest by using salient stimulus codes without jeopardizing the search performance of remaining, unhighlighted symbols. A balance must be achieved in this regard: Unhighlighted target tracks on a tactical display can quickly become crucial components in a tactical situation, and a coding scheme which shifts attention to such a degree that unhighlighted tracks are ignored is not optimal.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NSMRL Report # 1161	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Submarine Medical Research Laboratory 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION Naval Medical Research and Development Command
6c ADDRESS (City, State, and ZIP Code) Naval Submarine Base New London Groton, CT 06349-5900	7b ADDRESS (City, State, and ZIP Code) National Naval Medical Command Bethesda, MD 20889-5044
8a NAME OF FUNDING/SPONSORING ORGANIZATION Same as 7a 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Same as 7b	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO: 65856N PROJECT NO: M0100 TASK NO: 001 WORK UNIT ACCESSION NO: 5003

11 TITLE (Include Security Classification)
(U) Preliminary Investigation on the Utility of Saturation and Brightness as Redundant and Non-Redundant Codes with Hue in Tactical Displays

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13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Interim	FROM ______ TO ______	1990 December 07	18

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Visual search; Color; Brightness; Saturation

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Two experiments were conducted to assess the relative benefits of redundantly and non-redundantly combinding the stimulus dimensions of saturation and brightness with hue in symbolic visual displays. Previous research has indicated that both saturation and brightness may be related to hue in such a way that a facilitation in search performance might be realized if these dimensions were combined in a tactical display symbology. Subjects completed extensive visual search paradigms on CRT based tactical displays. In experiment 1, three hues (red, blue, and yellow) and three saturation levels (most, middle, and least saturated) were varied, while symbol shape was held constant. The stimulus combinations of hue and saturation were combined in redundant and non-redundant conditions, which enabled the quantification of the integrality and separability of the hue and saturation dimensions. The analysis of the search reaction times and the number of correct responses revealed a significant interference effect when the stimulus

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT XX UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL Susan D. Monty, Publications Office	22b TELEPHONE (Include Area Code) (203) 449-3967 22c OFFICE SYMBOL 421

DD Form 1473, JUN 86 Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 UNCLASSIFIED

19. Cont'd.

dimensions were combined in a non-redundant manner and the subjects were forced to search for targets of a specific saturation level. Compared to simple one dimensional search conditions, search performance was not improved when saturation was redundantly coded with hue, thus an integral facilitation effect was absent from the data. Based on the results of experiment 1, the use of different saturation levels within a hue may be ill-advised for applications in military tactical displays and civilian air traffic control. The presence of interference without facilitation argues for the exclusion of saturation as a separate or redundant coding dimension in tactical displays. In experiment 2, the three hues were varied with three stimulus brightness levels. The results were similar to those of experiment one, except that the interference effect in the non-redundant coding condition was due primarily to the medium brightness levels. If restricted to two levels, brightness might be a useful redundant code. Overall, the results lend support to algorithms that work to maximize color differences (in the CIE space) for use in visual displays.